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STATISTICAL INVESTIGATIONS OF THE OPERATIONAL LOADING OF THE LANDING GEAR OF A MAIN-LINE AIRCRAFT

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STATISTICAL INVESTIGATIONS OF THE OPERATIONAL LOADING OF THE LANDING GEAR OF A MAIN-LINE AIRCRAFT

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ABSTRACT. A determination is made of statistical data characterizing the load spectrum on the landing gear of the AN-10 aircraft during various phases of a typical flight. It is shown that up to 82% of all fatigue failures are caused by taxiing, and that changes in aircraft weight within typical service conditions have practically no effect on the fatigue life of landing gear. The loads acting on the landing gear differ for each individual concrete runway (and taxiway), and are highest for unpaved runways. An increase in taxiing speed from 25 to 50 km/hr on the same concrete surface leads to a 35% increase in fatigue damage to the landing gear, while a further increase in speed tends to decrease the fatigue load.

Reliable operation of aviation structures throughout a predetermined service life depends on many factors, one of which is fatigue durability. /52[1]

The durability of structures can be determined by performing natural fatigue testing. The most complete reproduction of the operating load spectrum possible during such tests is one important condition which must be met if reliable data on the actual operational durability of the structures are to be produced.

Information on operational loads can be produced by measuring these loads during flight strength testing. Depending on the conditions of operation, the operating loads vary over a broad range [1, 2]. In presenting data on loading produced in a limited flying experiment, we should consider all possible combinations of various operating conditions of aircraft during flights. In connection with this, we must investigate the influence of the primary operational factors on the loads borne by the structures, allowing us to select representative operational spectra. Also, since aviation structures are loaded by random loads, we must also solve problems of the statistical estimation of the necessary volume of experimentation and the degree of reliability of information produced.

This article is dedicated to an investigation of this problem. As an example, we shall use the vertical loading of the landing gear of the AN-10

[1] Numbers in the margin indicate pagination in the foreign text.

aircraft. The basis of the study shall be the results of flying strength tests of the AN-10 leading aircraft performed by us and the State Scientific Research Institute for Civil Aviation in 1964-65. The flight program of the leaders reflected the actual conditions of operation of aircraft in use in civil aviation.

Data on the loadings were systematized by a two-parametric method of calculation of the repetition of mean and amplitude values of cyclical loads, recorded on oscillographic tape.

The damage to structures is frequently estimated using the results of comparative calculations of values of fatigue damage to elements by linear summation of such damage events. In applying this method, we used endurance curves of the elementary structural elements used in the chassis from the materials of ZOKhGSNA[1] [3]. In order to produce a complete endurance diagram, the endurance curves were reconstructed according to the method described in [4].

Systematized data on loads were recalculated as applicable to the conditions of an average normal flight of AN-10 aircraft in airliner use [7]. The main stages of loading of the chassis in a normal flight are taxiing and running. We assume that the average duration of taxiing is eight minutes, /53 while the landing run begins at the moment the wheels touch the ground and ends when the velocity is decreased to 75-80 km/hr, and the takeoff run begins when the aircraft moves away from the takeoff run starting position, and ends when the wheels leave the ground.

Over 300 recordings of the processes of loading in various stages of a typical flight were made in 18 airports in the USSR.

The amplitude values of loads were represented in the form of curves of integral repetition (Figure 1). Here and in the following we will show the repetition H_a in logarithmic scale, and the chassis load P_{ya} in linear scale. The summary curve of load repetition over the entire flight [1] is close to the curve characterizing loads during taxiing [2], indicating the decisive significance of the taxiing stage under normal operating conditions. The repetition of loads during taxiing is seven to ten times higher than during landing.

The mean values of loads, our analysis showed, are distributed normally during all three stages, which allows us to compare the loading on the landing gear by amplitude values alone.

In calculating fatigue damage to structures, we considered both amplitude and average load values. The calculations showed that of the total amount of fatigue damage to a landing gear during an average typical flight, 82% occurs

[1] ZOKhGSNA -- expansion unknown.

during the taxiing process, 14% during the landing run and 4% during the takeoff run. Approximately the same figures were produced abroad in tests of the Varsity aircraft [5]. The main stage in a typical flight, causing the greatest fatigue damage to the structure of the AN-10 aircraft chassis, is the taxiing stage, which will be given particular attention in the following.

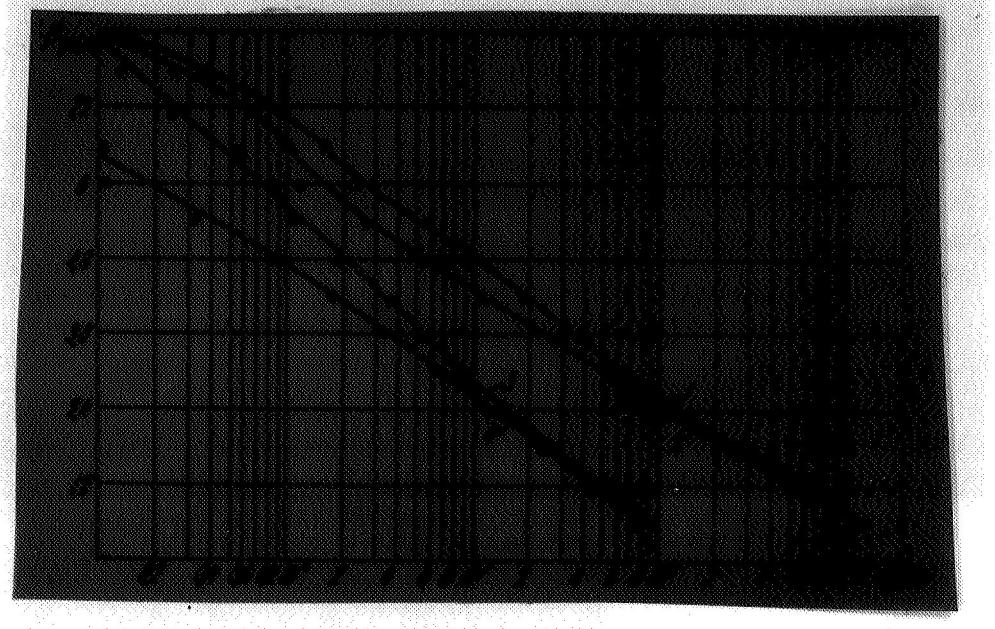

Figure 1. Integral Repetition of Load Amplitudes P_{va}. 1, Mean typical flight; 2, Mean typical taxiing; 3, Mean typical landing run; 4, Mean typical takeoff run

It was assumed in our investigation that the load on the chassis elements depends on the weight of the aircraft, the form and condition of the runway and taxiway and the taxiing speed.

The influence of each of these factors determining the operating conditions was analyzed with fixed values of all other factors. It was established that the fatigue loading on the landing gear of the aircraft is almost independent of any change in aircraft weight within the range characteristic for actual operating conditions (10-15%). This made it possible in subsequent calculations to ignore weight changes. /54

The influence of the type of runway and taxiway was studied or the basis of recordings of loads at each airport. The taxi speed was approximately the same in all cases. Figure 2 shows the curves of integral repetition of load amplitudes produced at ten airports with concrete runways and taxiways. The differences between the repetition of amplitudes at airports with concrete pavement are considerable, reaching an order of magnitude. Curve 1 averages these results. It was considered subsequently that this curve

characterizes the loading on the landing gear as the aircraft moves around an average, typical airport with concrete runway and taxiway.

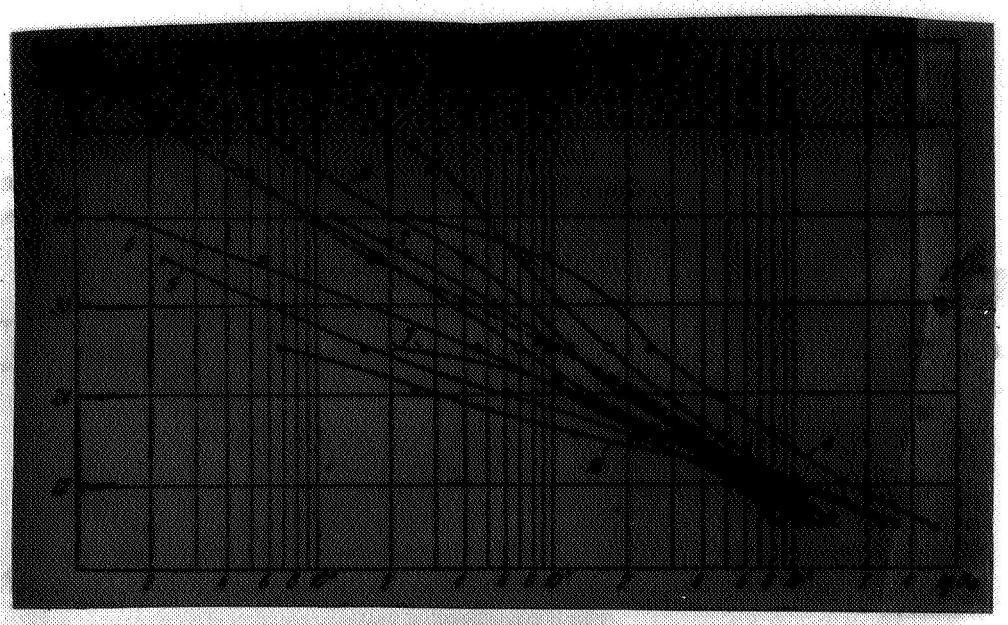

Figure 2. Integral Repetition of Load Amplitude P_{ya} During Taxiing in Airports with Various Coverings for Runways and Taxiways. 1, Average, typical airport with concrete runway and taxiway; 2, Concrete runway and taxiway at airport Kh; 3, Earth taxiway at airport Kh; 4, Earth taxiway at airport D; 5, Concrete runway and taxiway at airport Z; 6, Concrete runway and taxiway at airport V; 7, Concrete runway and taxiway at airport B; 8, Concrete runway and taxiway at airport S; 9, Concrete runway and taxiway at airport L; 10, Concrete runway and taxiway at airport A

The fatigue damage to the landing gear produced by calculation using cumulative theory may differ for various airports with concrete runways and taxiways by approximately 12-17 times. These results indicate the necessity of studying the factors causing these essential differences in loading and damage to aircraft landing gear during operations at different airports with concrete runways and taxiways. The microprofile of the pavement surface is quite significant here. This problem should be a subject of further investigations.

When operating on earthen fields, the loadings are considerably greater than when operating on concrete fields. For example, with an amplitude P_{ya} = 6 t, the repetition of loads at airports with concrete pavement is approximately one tenth that of airports with earthen fields (curves 1 and 10

on Figure 2).

Depending on the concrete conditions at the airport, the aircraft crew /55
may vary the taxiing speed over very wide limits. Calculations were performed to determine the influence of taxiing speed of the loading and damage to the structures in question. Mean estimates were produced on the basis of six to eight oscillographic recordings with each mean taxiing speed at the same airport. On this basis, we determined the repetition of loads during taxiing along the taxiway of the mean typical airport, the length of which was 2 km. In doing this, we used data on taxiing regimes produced earlier at KIIGA[1] [7].

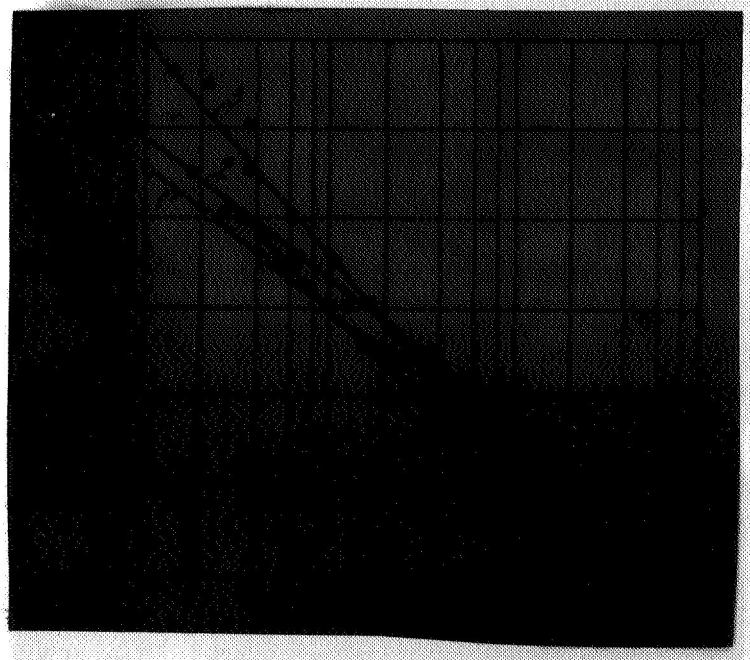

Figure 3. Integral Repetition of Load Amplitude P_{va} As a Function of Taxiing Speed. 1, V = 25 km/hr; 2, V = 35 km/hr; 3, V = 50 km/hr; 4, V = 65 km/hr

Figure 3 shows curves of the integral repetition of load amplitudes on the landing gear at various taxiing speeds. As the taxiing speed is changed from 25 to 50 km/hr, the repetition of amplitude values of loads at high load levels differs by 3-5 times. As the taxiing speed is increased, the repetition of loads increases, although after a certain speed is reached (in this case V_{av} = 50 km/hr), this dependence is inverted -- the repetition of loads begins to decrease (curve 4, Figure 3). When the taxiing speed exceeds 50 km/hr, the reduction in landing gear load repetition leads to a considerable decrease in fatigue damage.

Figure 4 shows the change in relative damage with a change in taxiing speed. The ordinate shows the relative value of fatigue damage a_v/a_{30}, where a_v and a_{30} are the fatigue damages at the given speed V and at speed V = 30 km/hr respectively. The greatest loading and fatigue damage to the

[1] KIIGA -- expansion unknown.

landing gear are observed at V = 50 km/hr, which can be looked upon as a critical taxiing speed V_{cr}.

Thus, in order to produce data on the operational loading of landing gear during the performance of flight strength tests, the actual distribution of taxi speeds must be considered. When fatigue damage to the landing gear of lead aircraft is to be forced, the taxiing speed used should be the critical speed. /56

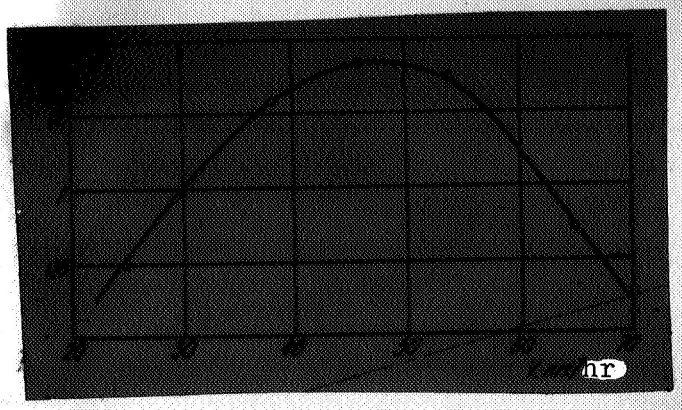

Figure 4. Relative Damage to Landing Gear Elements As a Function of Taxiing Speed

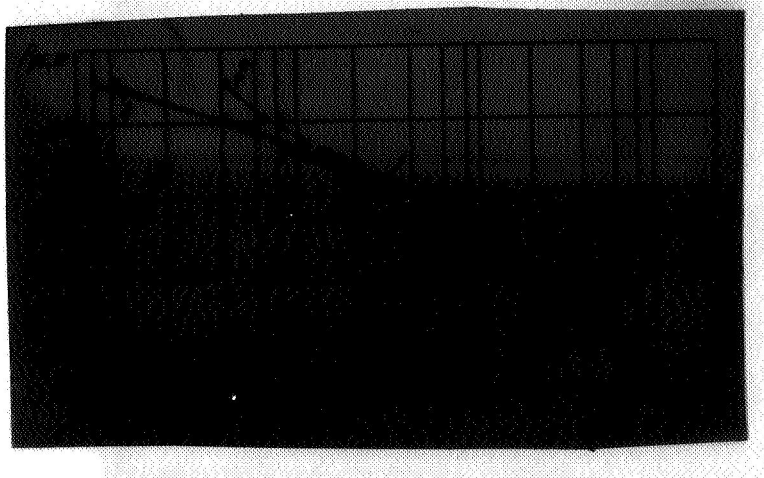

Figure 5. Integral Repetition of Load Amplitude P_{ya} with Various Volumes of Information. 1, Standard taxiing 38 sec; 2, Standard taxiing 115 sec; 3, Standard taxiing 385 sec; 4, Standard taxiing 566 sec

The degree of reliability of the results of investigation of operational loadings depends to a great extent on the volume of the experimental material. The greater the volume of the statistical data, the higher the reliability. However, increasing the duration of flying tests without reason involves unjustified expenditures of time and funds. We must establish the minimum volume of information which can be used to estimate the reliability of the results produced with the required probability.

Usually the necessary volume of experimental data is estimated by constructing curves of integral repetition with various durations of measurement of the quantity being analyzed, corrected to the stage of the average typical flight being investigated. It is assumed that the experimental volume required has been reached when the curves of integral repetition remain practically unchanged with further increases in volume. For example, Figure 5 shows curves of integral /57

repetition of amplitudes with typical taxiing based on selected experimental data produced with varying volumes of experimentation (from 38 to 566 sec). All of these data relate to a single airport and were produced during taxiing at speeds V_{av} = 35-40 km/hr. As we see, as the experimental volume increases, differences between curves decrease. An experimental volume of 400 sec can be assumed sufficient.

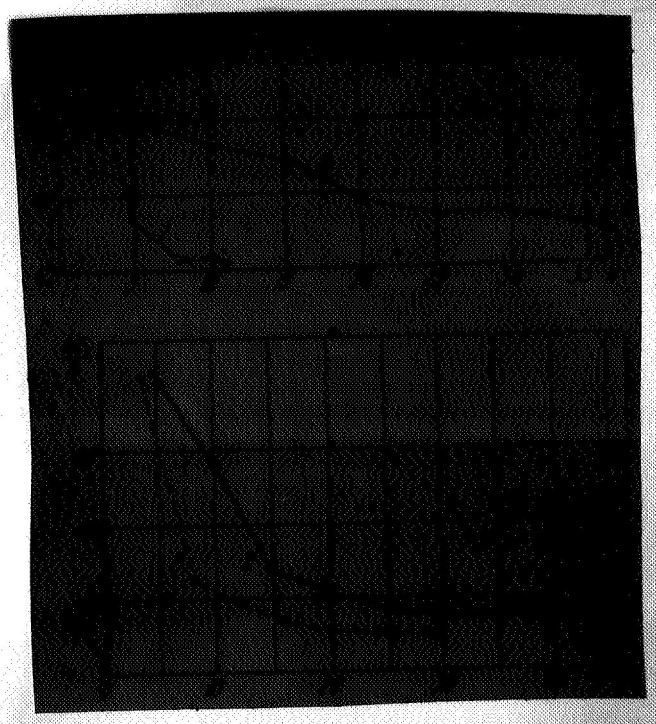

Figure 6. Relative Confidence Intervals of Fatigue Damage to Landing Gear Elements. a, Normal taxiing; b, Normal runs; 1, Taxiing in one airport; 2, Taxiing in 12 airports investigated

This method of comparison, however, does not give a probability evaluation of the information produced concerning random quantities such as fatigue damage a_i or integral repetition of amplitudes at a given load level H_a, which, depending on the volume of information available, will have varying confidence intervals of average values at a given probability.

Figure 6a shows the confidence intervals of relative repetition $\Delta a/\bar{a}$ for chassis with probability P = 0.95 for taxiing of the AN-10 lead aircfaft at one airport (curve 1) and at twelve other airports (curve 2) using the Student distribution [6],. as the distribution best describing processes with small samples. The abscissa shows the number of recordings n corrected to standard taxiing, while the ordinate shows the relative width of the confidence interval $\Delta a/\bar{a}$, where Δa is the width of the interval, $\bar{a}$ is the mean value of fatigue damage.

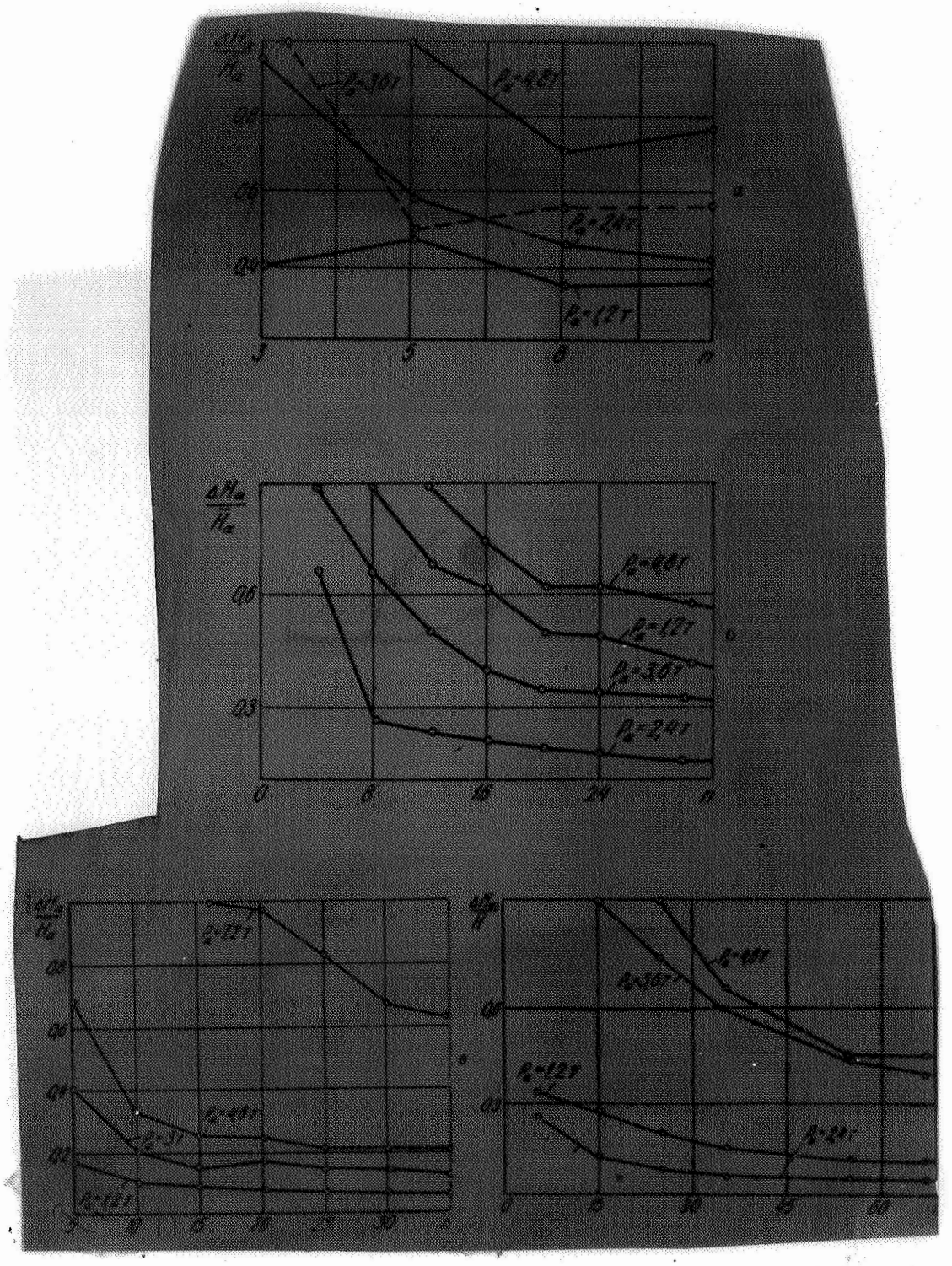

Figure 7. Relative Confidence Intervals of Integral Repetition of Load Amplitudes. a, Taxiing at one airport with V = const; b, Taxiing at one airport with V ≠ const; c, Taxiing at one airport; d, Taxiing at 12 airports with V ≠ const

As we can see from Figure 6a, as the number of recordings in each regime increases, the width of the confidence interval decreases. The rate of this decrease is itself decreased with an increasing volume of experimental material. Therefore, we can indicate a certain experimental volume, above which no essential increase in accuracy of data on fatigue damage can be achieved with the level of experimental accuracy used. For example, for taxiing in several airports (V = 30-45 km/hr) n = 25-35 recordings; for taxiing at one airport with constant velocity, n is 8-10 recordings. /59

Analogous confidence intervals for quantitative determination of the sufficient volume of information have also been composed for the running stages (Figure 6b). A sufficient number of landing runs n during landings at various airports was found to be 30-35, for one airport n = 20-25.

The value of relative confidence interval width is a characteristic of the reliability for a given volume of information in evaluating fatigue damage to the landing gear element in question with fixed probability P.

The problem of using the method of confidence intervals to estimate the sufficient volume of information concerning integral repetition of load amplitudes is made more complex by the fact that we have in this case a set of curves for various amplitudes. Therefore, for each value of amplitude at the probability used we must construct a separate confidence area.

The changes in relative values of integral repetition $\Delta H_a/\overline{H}_a$ at the amplitudes selected for the landing run stage (Figure 7c) and the taxiing stage (Figure 7a, b, d) performed at one and at 12 airports, give us a quantitative estimate of the necessary volume of experimental material.

Conclusions

1. Statistical data are produced characterizing the load spectrum of the AN-10 lead aircraft during various stages of an average typical flight. From the point of view of fatigue damage, the principal stage is taxiing (up to 82% of damage).

2. Changes in aircraft weight within the normal operating range have no essential influence on fatigue loading of the landing gear.

3. Various concrete runways and taxiways transmit different loads to the landing gear. For individual airports, the differences in landing gear loading may fluctuate by factors of 10 to 17. The highest loadings are those at airports with earthen runways and taxiways.

4. Increasing the taxiing speed from 25 km/hr to 50 km/hr at the same standard airport with concrete runways and taxiways causes an increase of the fatigue damage of landing gear elements of 35%. Further increases in taxiing speed decreased the loading.

5. The reliability of information on the operational loading depends on the experimental volume used. In order to achieve a probability P = 0.95, it is necessary to use an experimental volume with fixed loading during the taxiing stage at one airport of n = 5-8 (V = const) or n = 25-35 (V ≠ const). If the measurements are performed at different airports, n = 40-50 (V ≠ const), and the relative width of the confidence interval for these volumes is a characteristic of reliability.

6. The usage of the confidence interval methods for probability estimate /60
of fatigue damage of the chassis elements and the integral repetition of amplitude values of loads allowed us to determine the necessary volume of information on landing gear loading or estimate the degree of its reliability with a fixed volume of information.

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